National/International Lab-partnerships for the Investigation of Low Temperature Poly/Epi-Silicon Thin Film Growth Using Metal Induced Crystallization

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Abstract

The photovoltaic research center (PRC) at the University of Arkansas established partnerships with national and international laboratories under the auspices of DOE and NSF programs to investigate low temperature metal induced crystallization (MIC) of silicon for solar cell and other microelectronic applications. The results of these partnerships are highlighted in this presentation. The samples were prepared at PRC where preliminary analytical characterization was also performed. High Resolution Scanning Electron Microscopy (HRSEM), Atomic Force Microscopy (AFM), plan-view and cross-sectional Transmission Electron Microscopy (TEM) and Electron Diffraction studies were carried out at the National Renewable Energy Laboratory (NREL), a DOE national lab and at the National Center for Electron Microscopy (NCEM), a DOE user facility. Depth profiling and elemental mapping using Scanning Auger Microanalysis (SAM) were carried out at the High Temperature Materials Laboratory of Oak Ridge National Laboratory (ORNL), a national DOE User Center. The DOE Lab Partnership award was instrumental in our collaborative research with National Physical Laboratory, India. This effort has recently been funded under the US/India International cooperation agreement between NSF (USA) and DST (India). The results obtained from these partnerships and collaborations have been presented in several international conferences and published in peer-reviewed journals. A very strong team of researchers that includes academicians, research scientists, graduate and undergrad students, experts from DOE national labs and user facilities, and international colleagues, has been developed that utilize state-of-the-art equipment to investigate the phenomenon of crystallization at low

temperatures. New devices and processes have been invented and patented. A few significant achievements are highlighted here.

Figure 1 shows bright field TEM images (taken at NREL) of the polysilicon films fabricated on glass substrates at temperatures below 450°C by MIC of unhydrogenated amorphous silicon (a-Si). Image A shows a single crystal grain of larger than 10 μm. Image B shows a single crystal grain (dark area) of larger than 6 μm surrounded by a randomly oriented polycrystalline Si (gray area). The selected area diffractions (SAD) of these two regions, shown in Fig. 1 Image B inset, clearly prove this claim. TEM done at NCEM and NPL also verified our results of large grains in these films.

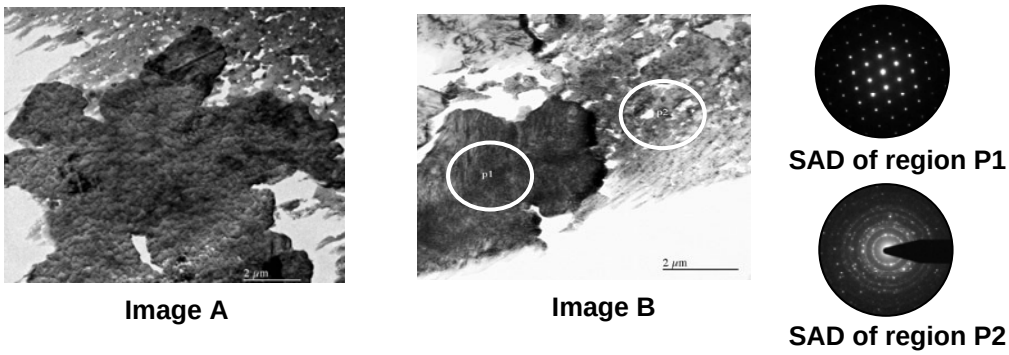

Fig. 1: TEM images of the crystallized films showing single crystal structure (region P1) and poly-Si nature (region P2). These images were taken at NREL.

Hydrogenated sputtered amorphous silicon (SP-a-Si:H) thin films were prepared at PRC. To study the effect of hydrogen on the crystallization process depth profiles of the annealed films were obtained. Scanning Auger Microanalysis (SAM) was conducted at ORNL. Fig. 2 shows the depth profile (a), and the elemental mapping for Al (b) and Si (c), at different depths from the surface. These also indicate grain sizes in excess of 20 μm.

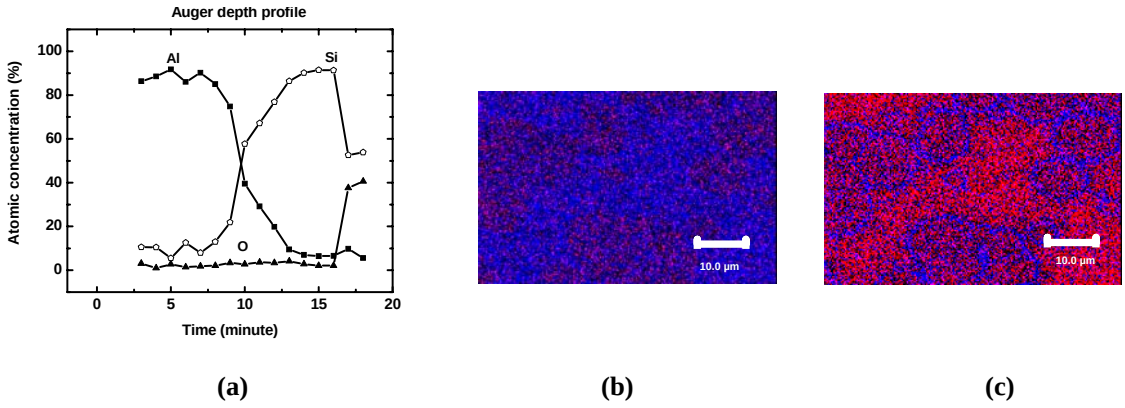

Fig. 2: a) Auger depth profile (conducted at ORNL) of a hydrogenated (14 at.%) sample annealed at 225ºC. b) SEM map showing Al as a top layer (blue). c) After etching 400 nm from the surface silicon layer appeared (red) with some Al showing in the grain boundaries.

Extensive TEM investigation of specimens fabricated at PRC was done in collaboration with NCEM. The collaboration involved a field trip by one of Ph.D. student to NCEM. The trip involved hands on training on TEM sample preparation and high resolution TEM operation. Fig. 4 Shows an XTEM image obtained in this research.

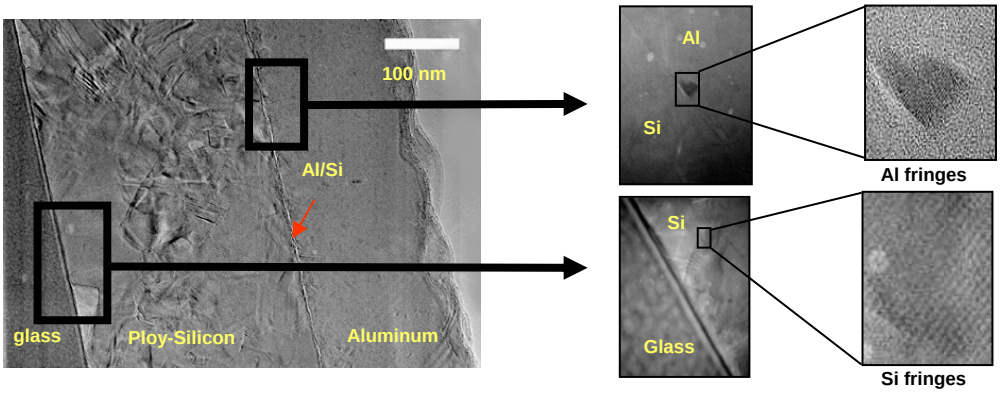

Fig. 4: XTEM image showing the layer sequence in the fabricated films. The fingers indicate the lattice structure in the films, therefore identifying the type of material in the film. This image is taken at NCEM

Another significant milestone achieved was the fabrication of epitaxial silicon films on crystalline silicon substrate at low temperatures using MIC. The films were deposited and crystallized at PRC and characterized using high resolution XTEM at NREL. Fig. 5 shows XTEM of the silicon films crystallized at 525°C for 60 minutes providing direct evidence of epitaxial film growth.

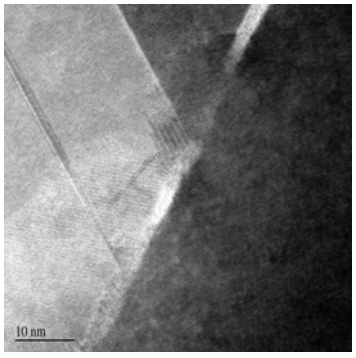

Fig. 5: XTEM images of a silicon film (grayish region) grown on c-Si wafer (dark region). The results show that the lattice orientation in the growing films is the same as that of the substrate. The distortions at the interface are properly caused by impurities or surface roughness. These images were taken at NREL.

The formation of isolated silicon nanowires (SiNW) and silicon nanowire networks using aluminum thin film was also investigated. SEM obtained at PRC revealed the formation of a continuous network of SiNW on the silicon wafer (see Fig. 6). Characterization of the nanowires composite was done using energy dispersive x-ray spectroscopy (EDS) at PRC. These results are unique in that the nanowires found are grown in a horizontal fashion instead of the more common vertical direction. Most of the nanowires have a diameter of about 60 nm and a length of over 10 μm.

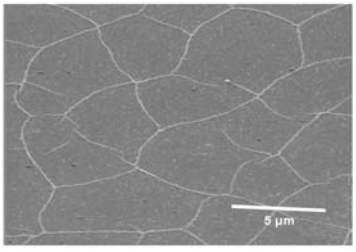

Fig. 6: SEM image showing the general morphology of SiNW network